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HUMAN CENTRED MANUFACTURING: METHODOLOGY FOR ERGONOMIC PREVISIONAL EVALUATION OF MANUAL ASSEMBLY OPERATIONS

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ABSTRACT

The challenge of flexibility and productivity for manufacturing operations needs a new concept based on “human-centered manufacturing process”. This concept must consider basically the ergonomics of workplaces and workload balancing. The application of this concept is achievable through the detailed knowledge of the interaction between human and workplace, in particular as far as the mechanical load (or work load) arising from product design and from manufacturing process definition (included tools and equipment). The measurement of workload then is a fundamental for new (and existing) workplaces. In this paper is described the methodology that considers the procedure and instruments for measuring ergonomic parameters and the use of EAWS method to assess the ergonomic risk level of the workplace summarized by a score. EAWS considers postural aspects and dynamics of work activity. Design or modification of the workplace can be defined on base of the results obtained by the methodology application.

Keywords: Manufacturing, Ergonomics, Human-Machine Interaction.

1 INTRODUCTION

The robotic and the automation aren’t able to solve problem of flexibility especially for a market that is characterized by a big number of niche volumes and a strong differentiation of the products inside the volume (mix of product). Manual work is a further and renewed possibility to face the problem.

The concept is to adapt the workstation to the work load acceptable for workers. It’s possible to do this by the use of EAWS (Ergonomic Assessment Work-Sheet) method. The method allows the ergonomic assessment of workplaces through a risk index already in design phase. This method (based on standard ISO 11228), applicable for ergonomic analysis of the workplace and for work distribution, requires a quantitative measure of several ergonomic parameters. Effectively, the EAWS method requires quantitative inputs like forces and postures, etc., for it to be correctly applied. The methodology of measurement and analysis of the ergonomic parameters is then an important part of the new concept. The objective is to better verify the ergonomics of the existing workplaces but also to use this data to carry out the design of manual manufacturing processes.

Through this methodology of measurement it is possible to know the interaction between the man and tools and to adapt the functionalities of the workplace to the capacities of a group of workers (Christmansonn 2000). The evaluation of mechanical load requested by the workplace (considering product and process together), is carried out in the working zone by the measurement of specific physical parameters necessary to perform the work activity. The measured parameters are then correlated with the anthropometry of workers, as well as with the method of work, the content of work (in terms of kind of operations requested for achieving a defined result) and the complexity of the work (in terms of precision and expected quality). Through a detailed and scientific measurement of several biomechanical parameters is possible also to carry out the mapping of the requested work-load and its distribution among workstations in a typical assembly line of automotive production system.

Information, data and knowledge about measurement are used to build fields of ergonomics database, and are also translated in an operative procedure for supporting the design and the development of advanced workplaces.

After some years of development and experimentation today is possible to adapt the biomechanical workload assigned to a workplace according to an expected "performance profile", in order to improve productivity and flexibility but also for increasing safety, ergonomics and wellbeing on the workplace.

2 METHODOLOGY DESCRIPTION

The methodology, finalised to the design of a new workstation for manual assembly operation, consists of six fundamental steps as follows:

1. *Workplace set-up:* is the first step necessary for the definition of the work activity (task and work method) and the work station configuration;
2. *Simulation:* is focused on work activity evaluation and can require a development of a mock up for physical evaluation;
3. *Measurement:* is the application of procedure for measurement and evaluation of ergonomic parameters and elaboration of gathered information;
4. *Risk analysis:* consists of calculation of the ergonomic level of the workplace through the use of EAWS method
5. *Modification:* is the phase of changing of the workplace set-up according to the indication from the step 4;
6. *Workplace validation*: is the verification of the modifications carried out and reporting.

2.1 Workplace set-up

The set-up of the workplace includes the definition (as designing hypothesis) of the geometry of the structure on which will be carried out the work, the lay out of the workstation and the work method (definition of tools and equipment included) to be used for the assembly operations. This step is useful for postures definition (according to the anthropometry selected for the workplace design) and for the work content definition.

2.2 Simulation

The simulation of the work activity is a step useful for visualization of postures and movement. It can be done by physical simulation by the use of a mock-up of the workplace or by the use of a virtual manikin like Jack, or equivalent tools. In the case of the building of a mock-up, the "mixed reality" can be used. The simulation (and the mock-up) enables the ergonomic parameters measurement in a laboratory context. The mock-up is concerning to the workplaces layout but also to tools and equipment.

2.3 Measurement

The step is focused on gathering information and data by the use of instruments for physical parameters detection like forces, pressure on the skin and angles related to postures. Measurements require a right calibration of sensors and their software, the evaluation of the technicality to allocate the sensors in order to collect the necessary information and not "dirty" information due to the manipulation of the sensors. The positioning of sensors between hand and tool or components to be manipulated is very important and needs to be evaluated also through a set of tests in laboratory environment before the experimentation on the mock-up (it can be adopted also for measurement on field) of the workplace. Another aspect to be considered is the variability among different people (anthropometry, force level exerted) and behaviours during the application of force or type of actions adopted for a task. The study of the "work method" before starting the measurement is very important to understand how to measure the phenomena we are analysing, and to decide how to set sensors. The whole procedure of measurement shown in figure 1 is fundamental to get information affordable and useful for ergonomic design; (Di Pardo *et al. 2012*).

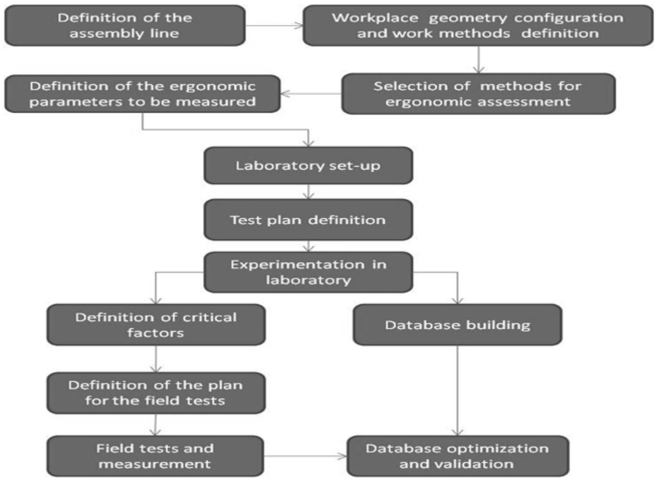

Figure 1: The procedure for measurement of ergonomic parameters.

2.4 Risk analysis

The risk analysis for whole body is carried out by the use of EAWS method. In this method there are 4 sections used for the ergonomic evaluation. Sections are: 1) postures of whole body, 2) actions with forces, 3) manual material handling, 4) movement of low load at high frequency. This method allows giving a score in function of several parameters. The risk index is based on a score with threshold values that make referring to the traffic light code (0-25 green, 26-50, yellow, >50 red). In this methodology the EAWS method is used to compare different solutions, from the first evaluation to the final optimisation. The advantage of such method is also due to the sections previously mentioned on which is possible to identify easily which factor is responsible of a high score of the risk index. Furthermore a modification can be evaluated only by changing of parameters of the section involved in the optimization.

2.5 Modification

After the first set-up of the workplace, a first analysis by EWAS method is carried out. If the evaluation is green, no modifications are necessary. If yellow or red evaluations, a modification of the workplace (or the mock-up) is necessary. Modification can involve the lay-out of the workplace, the tools used, the work method and finally, even the product.

2.6 Workplace validation

After the analysis of ergonomic parameters step by step, it is also important the valuation of the improvement gained from the first approach to the last optimisation. To do that is useful to use the following ratio of risk index $R = (I_f - I_i)/I_i$, where I_i is the score of the first hypothesis (I initial) and I_f is the score after the last modification (I final). This ratio gives us the dimension of the improvement.
The validation is carried out by a group of expert people who can judge the quality of the set-up defined after the complete design phase.

3 THE CASE STUDY

The methodology described in the above paragraph was applied to the case study: “new plastic bushes for holes sealing of a car door panel”. Two innovative bushes were evaluated: the pink version and the yellow version (figure2). Differences between the two versions are only the wing fastener along the body of the bush (shorter and continuous for the Yellow version; longer and cut near the bush’s head for the Pink version).

The objectives were the evaluation of the forces exerted during the assembly of new bushes and the evaluation of tool handling in order to select the best solution or to suggest the improvement for the tool and/or the work method.

The *setup of workplace* was made by referring to a typical assembly operation carried out in the final assembly line of a car industry. Posture and tools adopted during work activity were evaluated.

Figure 2: The new plastic bushes (P-pink & Y-yellow) with gasket and water sealing.

The *Simulation* of the work activity, on the mock-up of the workplace, was carried out at the ERGOLAB of Fiat Group Automobile (FGA) and some samples of the plastic bushes were developed by supplier in agreement with the department of product engineering of FGA. The test was carried out by seven repetition of measurement for each configuration and by the use of three different operators.

The *Measurement,* including the set-up of the procedure, the instruments calibration and the study of the work method for sensors positioning, was done at CRF (Laboratory for Ergonomics of Factory). The instruments used for this evaluation were electro-goniometers for the posture detection and two piezoresistive sensors for pressure/force detection (figure 3):

- the “FlexiForce® sensors” measure finger pressure and force using a small sensing area (9.53 mm of diameter) with a good linearity error (<3%). It is very flexible (0,2 mm of thickness).
- the “Grip™ system” measures static and dynamic pressures in the grasping of objects and it is mainly used for the tool handling evaluation. It is made of a thin, high-resolution pressure sensor with a sampling rate up to 500 Hz. The sensor has eighteen sensing regions that can be individually positioned over important anatomic sections of fingers and palm. Sensor is covered by a cotton glove usually used in production plant.

Figure 3: The force sensors used; Gryp system (and the glove with sensors) and the Flexiforce

The *Risk analysis* was carried out considering the posture depending from the lay out of the workplace of the assembly line and the possible tool modifications. The calculation of the risk index was made by using EAWS method. The type of grasp and the tool handgrip were also considered.

The *Modification* was carried out on the handgrip of the tool used for inserting the bush. In the figure 4, S_1,S_2 and S_3 on the tool handgrip are the contact surfaces between the hand and the handgrip itself (Types 1, 2 and 3). Specific pressure on the skin is then depending on the contact surface area. The bushes modification was already defined with the product designers.

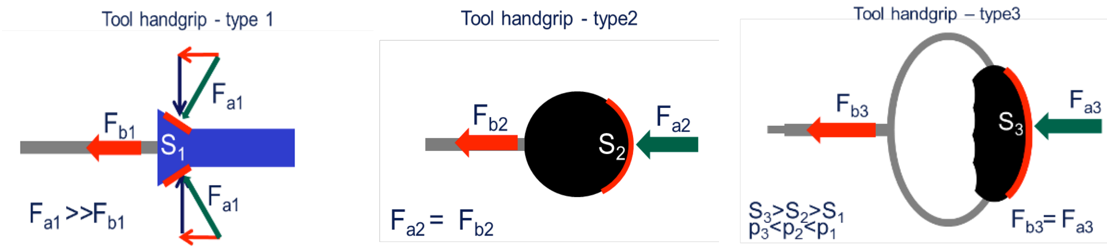

Figure 4: Tool handgrip of three different solutions evaluated

The *workplace validation* was defined according to the index ratio described before. In this case the posture of the whole body does not change and has no influences on the calculation. Forces exerted are depending on the version of the bush used. Types of grasp, as well as the specific pressure on the hand, are depending on the shape of the tool's handgrip. An interview to the operator at the end of the testing phase was also carried out.

4 RESULTS

The two bushes evaluated require different effort for their insertion and give also different feedback in tactile perception. The wing fastener of the pink version allows perceiving a "click" when the insertion is completed. The yellow version doesn't give feedback. As visible from the diagram in the figure 5 (got directly by the sensor during the measuring of the insertion), there are two instants in which the force decreases (zones 1 and 2). The first decrease (zone 1) is after the force necessary to achieve the assembly (F_insertion) of the bush. It's perceived by a click that means the achievement of the locking of the bush. The second decreasing (zone 2 in figure5) is after the maximum force (F_max) exerted by the worker before to stop his action at the end of the task. If there isn't the perception of the click (as for the yellow version of the bush), the worker, to be sure of the locking of the bush, pushes with a higher force (F_max) with respect to the insertion with feedback .

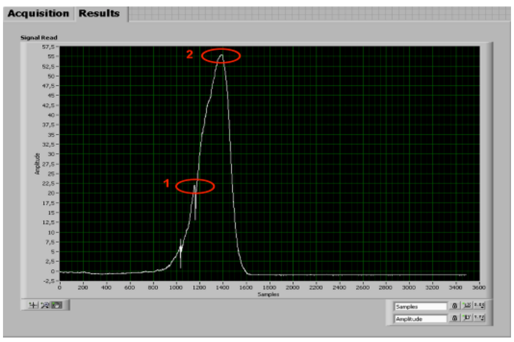

Figure 5: Force measured by the senor during the insertion of a fastener

This can be also seen by the two level of the force described (F_max and F-insertion) in the figure 6. On the left side of the figure 6 there is the table of references of forces used in the EAWS method.

The results in terms of forces measured by the sensors are reported on right side of figure 6 and two aspects have to be highlighted. The first aspect concerns the upper diagram in which the force is exerted by the finger (for the two kinds of bushes) and the second aspect concerns the lower diagram where the force is exerted by the use of three different tools (types 1, 2 and 3). In both cases forces have to be compared with the forces of the EAWS table, according to the type of grasping used (finger or "power grip" for the tool). No influence of the force is due to the gasket/sealing for the P-bush.

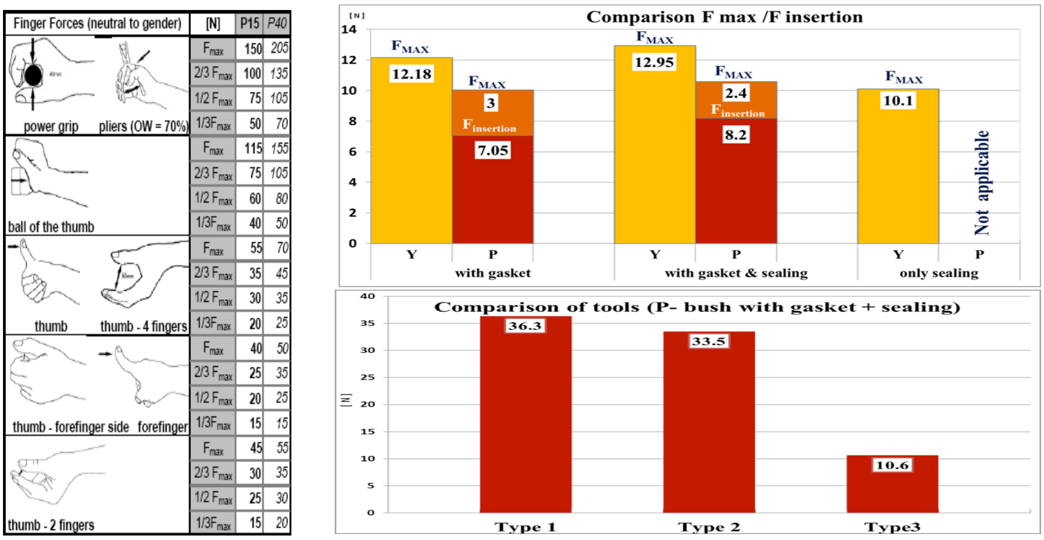

Figure 6: Table of EAWS method for force references and measured forces in mounting of bushes (Y= yellow, P= pink).

Because the evaluation is carried out to define a new possible solution (design) the column (on the EAWS table) to which make reference is the P15 (15 percentile) because more protective for workers. Considering these results in relationship to the different shapes of the handgrip of the tools, the following consideration can be done. The forces exerted with and without sealing are higher for the yellow version, so the better solution is the pink one. If we consider the best solution as far as the geometry of the bush, the use of a tool is recommended. Same force exerted with finger or with tool, leads to a comparison with different value of the force on the EAWS table. The calculation of the “R” ratio shows a significant reduction (about 20%) of risk index, if the handgrip type 3 is selected in respect to the type 1. (Both solutions were in the green area of the risk index). The handgrip type 3 of the tool is better than the type 2 and 1 because allows a good grasp and because the local pressure on the hand is lower.

5 CONCLUSION

The work carried out on a simple component can put in evidence the possibility to use objective methodology of analysis for the design phase based on measurement of ergonomic parameters. The design phase concerns the development (or the selection among different possibilities) of components (bushes in this case), as well as the design of an optimized tool for assembly of components. The same approach can be used in the case of the work-method design or in the case of the workplace layout design (in which postures of whole body are mainly involved). The EAWS method, because based on quantitative evaluation of ergonomic parameters (like forces), is a powerful method for design and set-up of workplaces. The methodology described above for measurement of forces as well as postures is another very effective way to proceed in the design phase definition.

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